ON THE ACCURACY OF 500 MB AND 300 MB ANALYSIS WITH SPECIAL REFERENCE TO NUMERICAL FORECASTING

BY

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PREFACE

The present dissertation is based on work performed at the Swedish meteorological and hydrological institute, Stockholm, and has been possible because of the generosity its Director, Dr Alf Nyberg, has shown me by putting part of the resources of the institute at my disposal.

I have had the privilege of working under two outstanding professors in meteorology, Tor Bergeron, Uppsala, and late Carl-Gustav Rossby, Stockholm. Professor Bergeron introduced me to one very stimulating realm of the science of meteorology, the synoptic meteorology with its intricate problems of analysis and forecasting. Professor Rossby, whose very inspiring lectures will never be forgotten by his pupils, introduced me to dynamic meteorology and I had the great luck to get an inside view during the first thrilling years of numerical forecasting.

During the long period of my research leading up to this dissertation, professor Erik Palmén, Helsinki, has always shown a great interest in my work and I have looked upon him as one of the great pioneers in synoptic meteorology.

Dr Bolin, Stockholm, and many of the scientists at the International Meteorological Institute, Stockholm, and the Institute of Meteorology, University of Stockholm, have been actively interested in my work and contributed to it by valuable discussions. Among all the personal of the Institute I owe a large debt of gratitude to mr Bo Döös whose generous and stimulating help made my work possible.

My colleagues at the Swedish meteorological and hydrological institute have demonstrated their interest in my work by helping me to receive the large number of upper air analyses that was necessary. Among them I would like to specifically mention mr Tore Duvedal, now chief meteorologist of the Scandinavian Airlines System, whose unselfish work with many problems connected with the machine computations mentioned in my papers made it possible for me to enlargen the scope of the investigation and to get it ready in a reasonable time.

Mrs Irma Wadsjö and miss Edith Wadsjö have made all the typewriting in connection with the dissertation and miss Margareta Cedrén is responsible for most of the drawing work.

To all contributors, named as well as anonymous, I express my sincere thanks.

Stockholm, September 1958.

Roy Berggren.

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SUMMARY

For many reasons it is of great importance to get a knowledge of the accuracy of upper air analysis. The possibility to forecast the future state of the upper air stream patterns is depending among other things on our capability to arrive at a correct picture of the initial state. This must be remembered when we consider the requirements of the civil and military aviation, especially after the advent of the high-altitude aircraft. It is a fact well-known to all synopticians that the analysis difficulties increase with increasing height of the pressure surfaces. The analysis of a 300 or a 200 mb chart exposes many intricate problems.

The importance of a good knowledge of the initial field is also to be remembered when considering the problems of numerical forecasting. Being an initial-value problem the numerical forecasting scheme used in connection with the papers discussed here rests heavily on the necessity to get a correct initial analysis of the stream function, approximated with the aid of upper air analysis of constant pressure surfaces.

If we go back to the problem of wind forecasting for aviation, it is interesting to investigate that variability of the wind field which is due solely to the personal factor in upper air analysis. Some analyses experiments were made in the following manner. Ozalid copies of 500 and 300 mb plotted charts were given to experienced analysts who were asked to analyse the charts independent of other analysts. All analysts were given a previous chart (24h before the actual observation time) and a weather chart (in the case of 500 mb analysis) or 500 mb chart (when analysing the 300 mb chart). The last-mentioned 500 mb chart was the analyst's own chart.

All variations discussed in paper I–IV are due to the fact that no unique solution of the analysis problem exists with the very sparse and qualitatively inadequate upper air network of today.

In paper I it is shown that in some cases the variation of the geostrophic wind is rather large and this is true not only at isolated points but for the mean wind over very long tracks as well. One example may be given. One analysis out of 26 gave a mean wind component of 20.2 m/s along a track 7500 km long, while another gave the value 26.5 m/s. For a track 3300 km long the wind velocity varied from 20.3 to 29.2 m/s.

In an aviation requirement list the figure 10 per cent is mentioned as a wanted accuracy of upper wind forecasts. It seems, however, difficult to develop forecast methods giving the wind speed with a 10 per cent accuracy taking the variability of the initial analysis into account.

Another way of indicating the differences between analyses is to compute the standard deviation of the height of the 500(300) mb surface at a number of points from the set of analyses available.

In paper I and IV such values are given for 500 mb. In paper IV is also given a discussion of the standard deviation computed for the 300 mb charts. The 500 mb values at different points varied from 2 to 44 m over an area 4200×8100 km, while the 300 mb values ranged from 3 to 65 m. Charts giving the spatial distribution are also given.

It is shown that a correlation exists between the above-mentioned standard deviation and the network density expressed with the aid of a function giving the distance from a point on the chart to the nearest radiosond station. The extreme values for the two quantities coincide in most places very neatly.

The comparison between the different analyses can also be made by computing the root-mean-square of the differences between point values on the charts.

In paper IV are given a number of values for this quantity and for the three different sets of charts used during the experiments. The number of analyses was 26(29), 23 and 22, respectively. The root-mean-square value varied from 16 to 42 m for 500 mb and from 21 to 53 m for 300 mb.

The values given in paper IV give rather large samples of this quantity, so often given in the literature on numerical analysis and forecasting. They may therefore serve as an indication of the variations that seems inevitable with the existing analysis techniques. It must not be forgotten, however, that the values given in paper IV represent just one 300 mb case and two 500 mb cases, respectively.

Going over to the question of numerical forecasting we notice that the problem of the variability of the upper air analysis enters in many ways. The different initial charts give different forecasts and different initial and verification charts give different changes of the height of the pressure surface in question. The observed changes of the height of the 500(300) mb surface are often correlated with the forecast changes and by taking another verification chart we may get a rather large change in the verification quantity. This change corresponds to no change whatsoever in the quality of the forecast itself. In paper I are given a whole set of verification parameters and their variability with the verification analysis. For the 24h forecast the correlation coefficient between observed and forecast changes varied between 0.56 and 0.65 for 26 analyses. The maximum value increased to 0.77 when a numerical analysis was included. (In paper I an explanation is given for the large increase of the correlation coefficient.) The root-mean-square of the difference between the forecast chart and the verification chart varied from 57 to 68 gdm. For the numerical analysis the value was 45 gdm. Finally, the correlation coefficient between observed and forecast changes in the geostrophic wind field varied from 0.34 to 0.49 (0.70 for the numerical analysis).

In paper II principally the same thing may be noticed, but in the cases discussed there the initial analysis varied.

In paper III a discussion is given of the variation in one grid point of the vorticity advection term (and the absolute vorticity). It is shown that the value of the advection term divided by the square of the absolute (geostrophic) vorticity varied from 0.28 to -0.17 MTS units. When using the vorticity equation to compute the vertical motion the above-mentioned expression enters into the computations and the given example shows that large variation in the vertical motion field may be expected if we take different analyses as basis for the computations.

In paper II some parameters are calculated for the 26 different analyses mentioned already. For an area of 2700×1800 km the standard deviation of the vorticity and the Jacobian J (η, ϕ) varied between $5 \cdot 10^{-5}$ and 10^{-5} MTS units and $33 \cdot 10^{-14}$ and $3 \cdot 10^{-14}$ MTS units, respectively.

The question of how variations in the initial charts are reflected in the forecasts have been discussed recently by some authors. In paper II a discussion is given, in which a slightly different approach to the problem is used. Four different analyses of one and the same 500 mb observation material are given and the forecasts made from them are compared in the following ways. In one case the boundary regions are kept identical, in one case the boundary regions are different, while the inner region is identical and in the third case the analyses are more or less different all over the forecast region. It was somewhat surprising to find that the differences between the forecasts based on the different analyses were rather small. As a matter of fact the differences were negligible for rather large areas of the 24h forecasts. The reason for the small differences may be two-fold. The first reason is the cancelling out of errors in computing second and third order derivatives in the process of solving the vorticity equation. The second reason is the small differences between the original analyses as the case was a simple one from an analyst's point of view.

The conclusions may be summarized as follows:

a) as the deviations in the initial analyses to a large extent show a definite correlation with the station network and reach very large values in regions of sparse data, it is necessary to increase the upper air network considerably, especially over ocean areas, if we want to increase the wind forecast accuracy significantly,

b) it is necessary to develop a better analysis technique for the upper air charts in order to minimize the differences. The personal latitude in analysis must be reduced,

c) it is necessary to use only well trained and very skillful analysts in the daily routine work. As the number of this type of meteorologists is and perhaps will remain small, one solution may be to organize large analysis centers. The ultimate goal must be, however, to automatize the work as far as possible. The work of the analyst (and forecaster) must be concentrated on the pertinent problems and not divided up in small portions, many of which are very time-consuming.

Errata

Paper I: p. 330, caption to fig. 7, first line: stands (σ), should read (σ_h)

p. 338, table V: the maximum value and the range of v_{yy} for row 10 should read 11.4 and 5.3, respectively. All through the paper the letters X and x have been mixed. In all cases, however, it may be inferred from the text whether X or x is meant.

p. 326 and 327, caption to fig. 2 b and 3 b, p. 332, second column, the last but eighth line from the bottom: the error of the forecasts is given in such a way that a plus sign indicates too high forecast values.

p. 332, first column, eighth line: stands ($x = 8$, $y = 4$), should read ($x = 4$, $y = 8$). Same column, ninth line: stands 60 gdm, should read 57 gdm.

p. 338, table VI: coord. $x = 17$, $y = 13$ should read $x = 6$, $y = 17$.